Searches for new physics in diboson resonances with the ATLAS detector at the LHC

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Contents

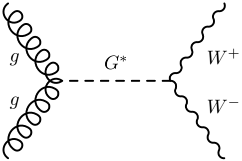
Physical Models Relevant to this Talk

- **Randal-Sundrum Based Model(RS I):** Predicting an extra compactified dimension, we search the lowest graviton mode, G^*.
- **Extended Gauge Model(EGM):** Predicting heavier versions of the W and Z bosons, the W' and Z'.
- **Minimal Walking Technicolor(MWT):** Particular version of Technicolor, predicts the existence of $R^{\pm}_{1,2}$ and $R^{0}_{1,2}$.
- **Low Scale Technicolor(LSCT):** Particular version of Technicolor, predicts the existence of a_T, ω_T and ϕ_T.
- **Heavy Vector Triplet (HVT):** Based on a phenomenological Lagrangian, the resonances searched are $V^{\pm}$ and V^0.
- **Georgi-Machacek Higgs Triplet Model (GMHTM):** Predicts the existence of charged higgs bosons $H^{\pm}$.

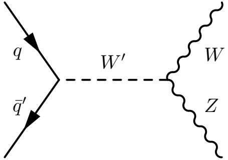
Physical Models Relevant to this Talk

Motivation

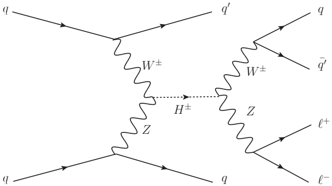
ATLAS data coming from $\sqrt{s} = 8$ TeV pp collisions is used to search for narrow diboson resonances and other predicted particles.



Randal Sundrum I model.



Extended Gauge Model.



GMHTM.

Hadronic Boson Reconstruction

Different clustering algorithms can be used for reconstructing the jets originating from a vector boson decay, depending on the boson p_T.

Hadronically Decaying Bosons

If the p_T of the bosons is low enough the two quarks in which they decay will hadronize in two well separated jets, this is the **resolved regime**.

LRR: If for both bosons $p_T > 100$GeV.

HRR: If for both bosons $p_T > 250(300)$GeV for ZV(WV) analysis.

If the p_T of the bosons is large enough the quarks from its decay will form a **single fat** jet, this is the merged regime.

MR: Merged regime, if for both bosons $p_T > 400$GeV. Enables the use of a split filtering algorithm optimized for high p_T jets, this algorithm is described in slide 30.

In order to reconstruct Higgs bosons b-jets are identified with a neural network based algorithm that achieves 70% efficiency.

Leptonic Boson Reconstruction

The analyses reviewed here follow roughly the requirements listed below when dealing with leptons.

Leptonically Decaying Bosons

- The leptons are required to pass isolation requirements in the Inner Detector and in the Calorimeter.
- The leptons are required to be isolated $\Rightarrow$ for boosted Z bosons decaying into two leptons l_1 and l_2, $\Delta R(l_1, l_2)$ is very small and many events fail isolation $\Rightarrow$ energy of l_2 has to be ignored when applying isolation requirements to l_1 and viceversa, this is an **optimized isolation** algorithm for boosted bosons.
- The lowest p_T of the electrons and muons should be above ≈ 25GeV.
- Electrons most of the time are required to be in $|\eta| < 2.7$ excluding $1.05 < |\eta| < 2.4$, the *precision region* of the Electromagnetic Calorimeter.
- Neutrinos p_T's are taken as the p_T^{miss} in the event and their p_z are obtained by requiring $M_W = M_{l\nu}$.

Search Channels

$WV \to l\nu jj/l\nu J$, http://arxiv.org/pdf/1503.04677v1.pdf

Event Selection

- Analysis triggers on events with one electron or one muon.
- It uses merged and resolved regimes to reconstruct hadronic bosons which should lie in $65 < m_{jj/J} < 105\text{GeV}$.
- $E_T^{miss} > 30\text{GeV}$.

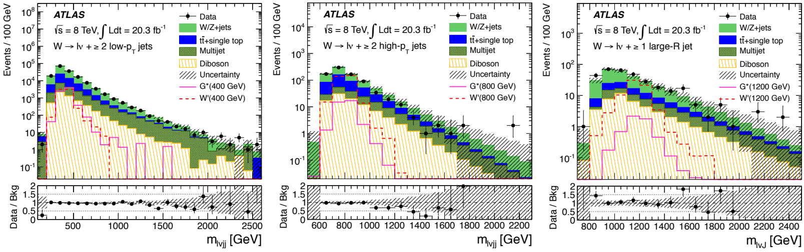


Figure: The figures show a comparison between the background estimate and the data. At the left for the LRR at the center for the HRR and at the right for the MR region.

$WV \to l\nu jj/l\nu J$, http://arxiv.org/pdf/1503.04677v1.pdf

Background Estimation and Limits

- The main background comes from W/Z+jets events
- This background is estimated with simulated samples corrected with data using control regions.
- For the control regions, the mass of the boson is restricted to the sidebands $40 < m_{jj} < 65$GeV and $105 < m_{jj} < 200$GeV of the LRR.

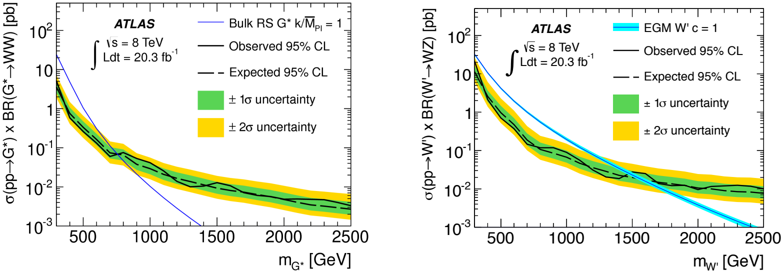
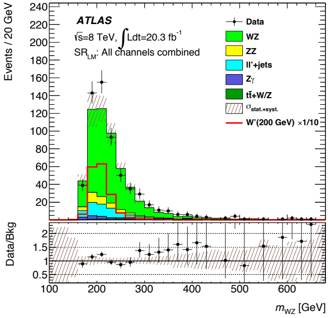


Figure: Upper limits on the $\sigma \cdot BR$ for a RS I graviton and an EGM W', combining merged and resolved regimes.

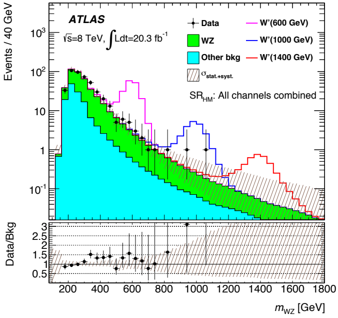
$WZ \to l\nu ll$, http://arxiv.org/pdf/1406.4456v1.pdf

Event Selection

- Exactly three leptons are required with a $p_T > 25$GeV.
- Two signal regions are defined, one for high mass signals (S_{HM}) with $\Delta\phi(l, E_T^{miss}) < 1.5$ and another for low mass signals S_{LM} with $\Delta\phi(l, E_T^{miss}) > 1.5$



Low Signal Region

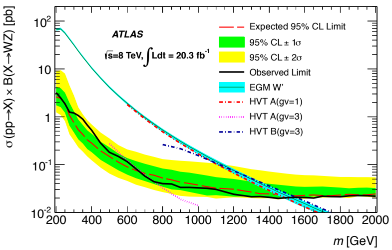


High Signal Region

$WZ \rightarrow l\nu ll$, http://arxiv.org/pdf/1406.4456v1.pdf

Background Estimation and Limits

- The background is dominated by WZ/ZZ and $t\bar{t} + W/Z$ events.
- The simulation modeling of these backgrounds is validated on a control region consisting of the $\Delta y(W, Z)$ cut reversed and the $\Delta\phi(l, E_T^{miss})$ dropped.



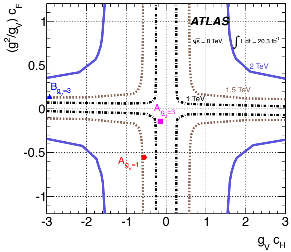
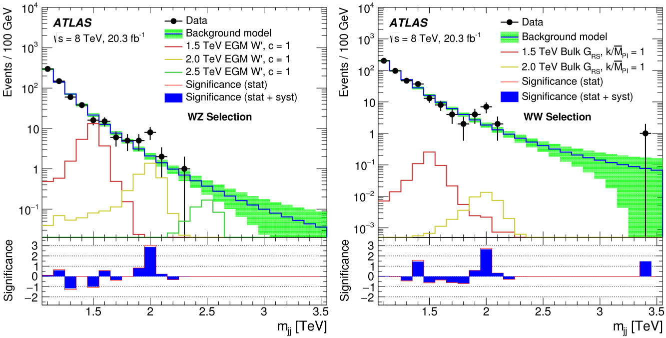


Figure: At the left the upper observed limits on the $\sigma \cdot BR$ for an EGM W', combining low and high signal regions. At the right the exclusion contours in the HVT parameter space.

$VV \rightarrow JJ$, http://arxiv.org/pdf/1506.00962v2.pdf

Event Selection

- Analysis triggers on events with a large-R jet with $p_T > 360$GeV.
- The analysis uses only the merged regime (due to the high p_T of the bosons) and substructure quantities are used to tag the bosons.
- The bosons are required to be within 13GeV from the mass of the W or Z, other cuts are applied on the jet's number of tracks, $\Delta y(J_1, J_2)$...



$VV \to JJ$, http://arxiv.org/pdf/1506.00962v2.pdf

Background Estimation and Limits

- The background is dominated by SM QCD dijet events with small contribution from $W/Z + jets$.
- The background is estimated by fitting the data, the systematics on the background come from the error in the fitting parameters.

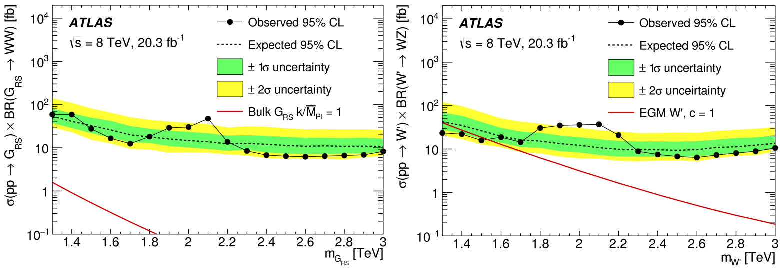
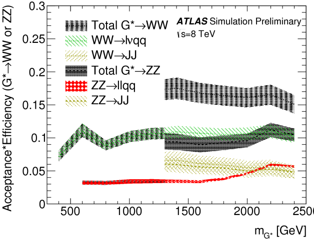
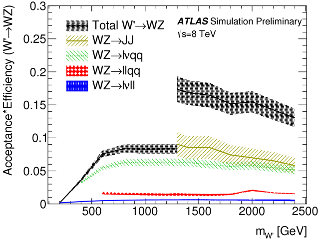


Figure: At the left it is shown the upper and expected limits on the branching ratio times the cross section for $G \to WW$. At the right it is shown the same but for the process $W' \to WZ$.

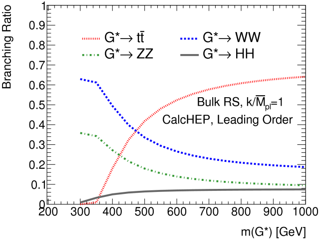
VV combination (Acceptance$\times$Efficiency and Branching ratios), Preliminary



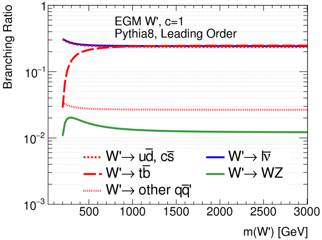
$G^* \rightarrow WW/ZZ$



$W' \rightarrow WZ$

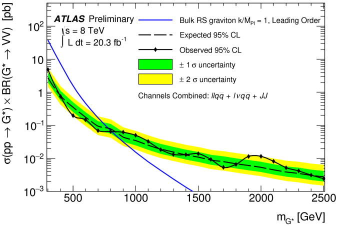


G^*

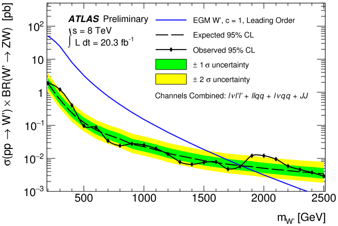


W'

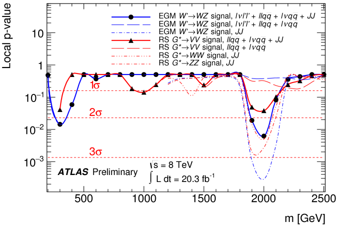
VV combination (Limits and pvalues), Preliminary



$G^* \to WW/ZZ$



$W' \to WZ$

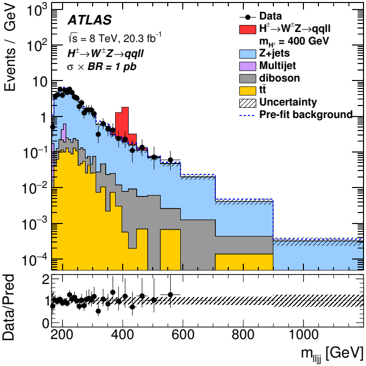


G^*

$H^\pm \to W^\pm Z$, http://arxiv.org/pdf/1503.04233v1.pdf

Event Selection

- The W boson, reconstructed from the highest p_T central ($|\eta| < 2.5$) jets, has to be in $60 < m_{jj} < 95$GeV.
- The Z boson, reconstructed from two leptons required to be oppositely charged, has to be in $83 < m_{ll} < 99$GeV.



$H^{\pm} \to W^{\pm}Z$, http://arxiv.org/pdf/1503.04233v1.pdf

Background Estimation and Limits

- The shapes of all the backgrounds are estimated from simulation, except the multijet background that is taken from data.
- The $Z + jets$ background normalization is left as a free parameter in the fit to the data.
- The largest systematic uncertainties come from the $Z + jets$ normalization and modeling.

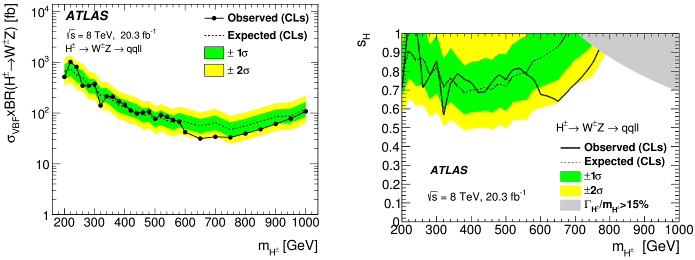
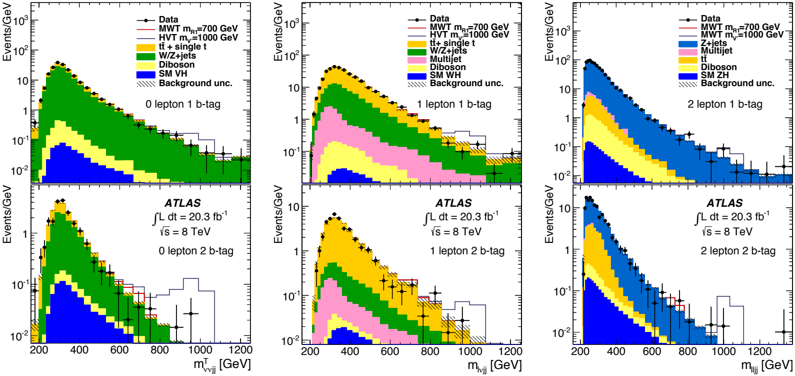


Figure: At the right the upper limits on $\sigma \cdot BR$ for a $H^{\pm}$, at the right the same upper limits for the model parameter S_H.

$VH \rightarrow \nu\nu/l\nu/ll + b\bar{b}$, http://arxiv.org/pdf/1503.08089v1.pdf

Event Selection

- The data is split into samples with 1 b-tagged jet and 2 b-tagged jets. AntiKt 0.4 jets are used.
- The Data is also split in three categories, events with zero, one and two leptons.
- A cut on the p_T of the boson as a function of the reconstructed mass was used.



$VH \to \nu\nu/l\nu/ll + b\bar{b}$, http://arxiv.org/pdf/1503.08089v1.pdf

Background Estimation and Limits

- All backgrounds except the multijet background are taken from simulation corrected with data in control regions.
- The $W/Z + jets$ and $t\bar{t}$ modeling are the dominant sources of systematics; they are obtained comparing different generators and by looking at any residual discrepancy in the control regions.

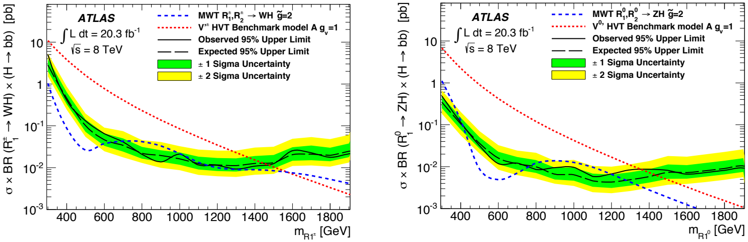


Figure: Limits on $R_1^{(\pm,0)}$ (Minimal Walking Technicolor) and $V^{(0,\pm)}$ (Heavy Vector Triplet).

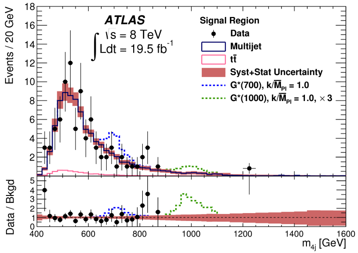
$HH \to b\bar{b}b\bar{b}$, http://arxiv.org/pdf/1506.00285v1.pdf

Event Selection

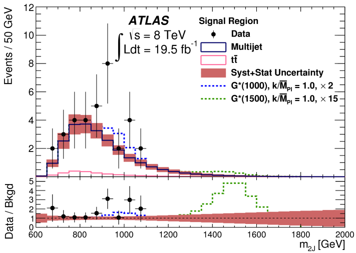
Merged Regime: Select events with two large-R jets, build from their tracks AntiKt jets with $R = 1.0$ and trim them, using $\Delta R = 0.3$ subjets to get rid of QCD, find b-jets among the subjets.

Resolved Regime: Select events with at least 4 b-tagged jets and form dijets with highest p_T jets, then apply mass dependent cuts.

The same b-tagging algorithm is used in both regimes.



Resolved Regime

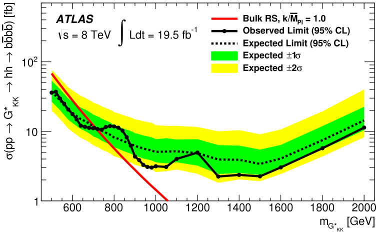


Boosted Regime

$HH \to b\bar{b}b\bar{b}$, http://arxiv.org/pdf/1506.00285v1.pdf

Background Estimation and Limits

- The background is dominated by multijet (95%) and $t\bar{t}$ (5%) events.
- The multijet background is modeled using data and the $t\bar{t}$ background uses simulation for the shape, the normalization is deduced using data.
- Boosted and resolved regimes are combined to achieve the highest sensitivity.



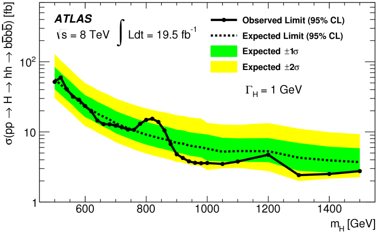


Figure: Upper Limits on $\sigma \cdot BR$ after combining the merged and resolved regime for the a Graviton (left) and a Heavy Higgs (right).

Summary

- Several searches have been reviewed in the diboson channel, they use the full 2012 ATLAS dataset of *pp* collisions at $\sqrt{s} = 8$TeV.
- The channels studied contain two bosons. These can be $W's$, $Z's$ or $H's$, which can decay into leptons or quarks.
- Boson tagging techniques are used for the resolved and merged regime when the boson decays into quarks.
- Optimized isolation criteria are used for boosted Z bosons decaying leptonically.
- Limits are set and many models are ruled out at 95% CL.
- No new physics has been found so far but an excess at 2TeV was found in the $VV \rightarrow JJ$ analysis with a global significance of 2.5σ.

Summary

All the searches listed here use the full 2012 ATLAS dataset. l stands for electrons or muons.

Channel/Model	Signals	Jets	Background	Paper
$WV \to l\nu jj/J$	W', G^*	AntiKt-0.4 C/A-1.2	MC+Data	link
$ZV \to lljj/J$	W', G^*	AntiKt-0.4 C/A-1.2	MC+Data	link
$VV \to JJ$	W', G^*	C/A 1.2	Data	link
$WZ \to l\nu ll$	W', V^0, $V^\pm$	–	MC+Data	link
$VH \to ll/l\nu$ $/\nu\nu + b\bar{b}$	$R^0_{1,2}$, $R^\pm_{1,2}$ V^0, $V^\pm$	AntiKt-0.4	MC+Data	link
$HH \to b\bar{b}b\bar{b}$	G^*,H	AntiKt-0.4 AntiKt-1.0	MC+Data	link
$V\gamma$	a_T, ω_T, ϕ_T	AntiKt-0.4	Data	link
$W^\pm Z \to jjll$	$H^\pm$	AntiKt-0.4	MC+Data	link

BACKUP

Results, Comparison with CMS

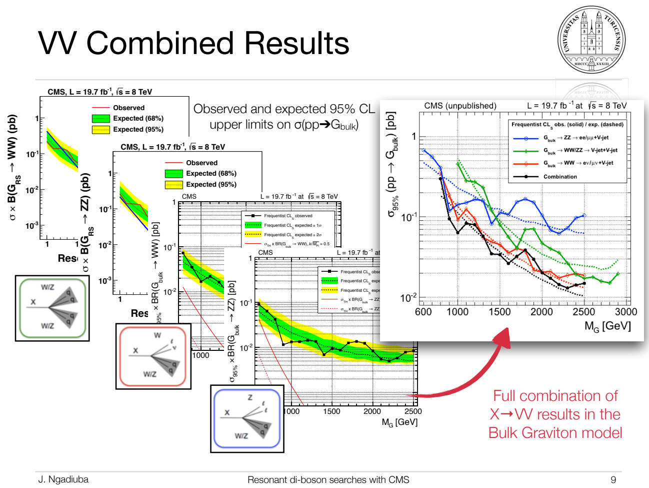
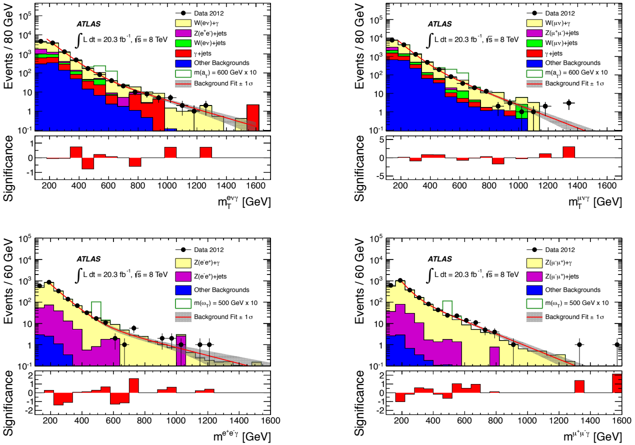


Figure: Presented by Jennifer Ngadiuba (University of Zurich) at PHENO 2015.

$V\gamma \to l\nu / ll + \gamma$, http://arxiv.org/pdf/1407.8150v2.pdf

Event Selection

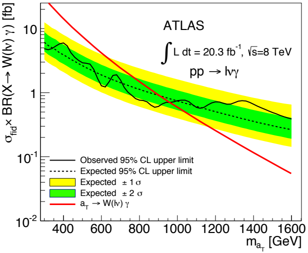
- The Z boson is reconstructed from leptons in $65 < m_{ll} < 115$GeV.
- The transverse mass of the reconstructed W has to satisfy $M_W > 40$GeV.

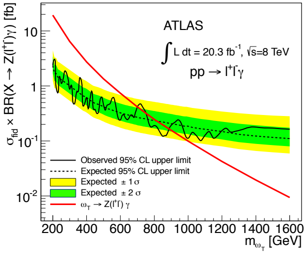


$V\gamma \to l\nu/ll + \gamma$, http://arxiv.org/pdf/1407.8150v2.pdf

Background Estimation and Limits

The background is made mostly of SM $W/Z + \gamma$, $W/Z + jets$, $\gamma + jets$, $t\bar{t}$, and it is calculated by fitting a sum of two exponentials to the data.



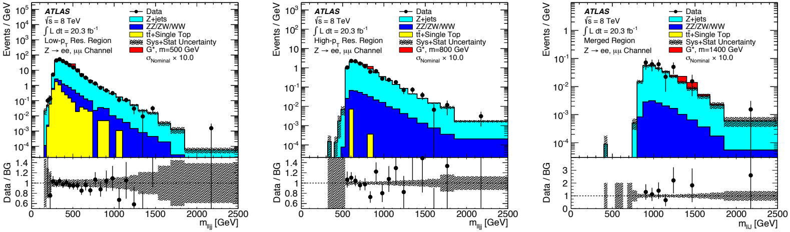


Observed upper limits on $\sigma \cdot BR$ for a_T and ω_T in function of their masses.

$ZV \rightarrow lljj/llJ$, http://arxiv.org/pdf/1409.6190v2.pdf

Event Selection

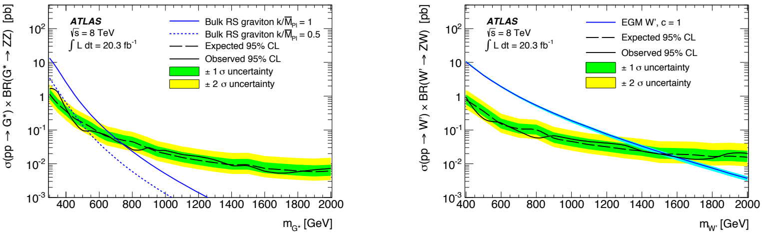
- The analysis triggers on events with one electron or one muon.
- It uses merged and resolved regimes to reconstruct hadronic bosons which should lie in $70 < m_{jj/J} < 110$GeV.
- Makes use of an **optimized isolation** cut for boosted Z's to reconstruct Z bosons which should lie in $66 < m_{ll} < 116$GeV.



$ZV \rightarrow lljj/llJ$, http://arxiv.org/pdf/1409.6190v2.pdf

Background Estimation and Limits

- The main background is Z+jets events.
- This background is estimated with simulated samples corrected using data in the control region.
- The control regions is taken as either $m_{jj/J} < 70\text{GeV}$ or $m_{jj/J} > 110\text{GeV}$.



Upper limits on the $\sigma \cdot BR$ for a bulk RS graviton and an EGM W', combining merged and resolved regimes.

Filtering C/A jets

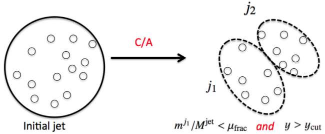
A split-filtering algorithm is used in WV, ZV and VV channels to clean C/A 1.2 jets from QCD contamination.

Filtered Jets

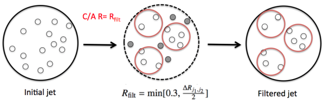
C/A 1.2 jets are made of calorimeter clusters. To get rid of QCD contamination, decluster C/A jets and keep pair if $y_f > y_{fmin}$, otherwise keep only hardest jet (groom). Repeat until a pair is found or until nothing is left, then recluster what is left with C/A R_{filt} and keep the 3 leading subjets.

$$y_f = \frac{min(p_{T1}^2, p_{T2}^2)}{m_0^2}\Delta R_{12}^2 \approx \frac{min(p_{T1}, p_{T2})}{max(p_{T1}, p_{T2})} \quad (1)$$

$$\mu_f = \frac{max(m_1, m_2)}{m_0} \quad (2)$$



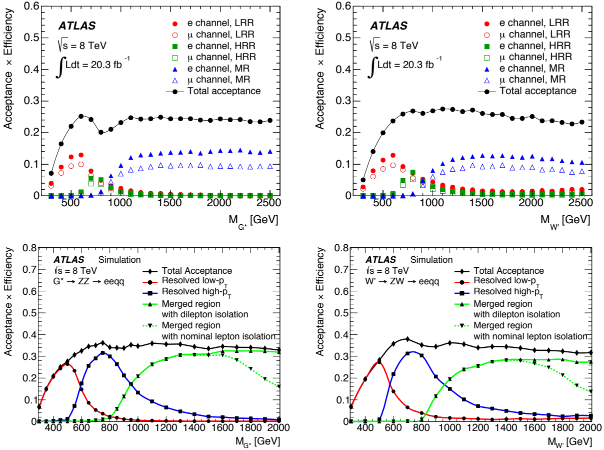
Splitting and Grooming



Reclustering and Filtering

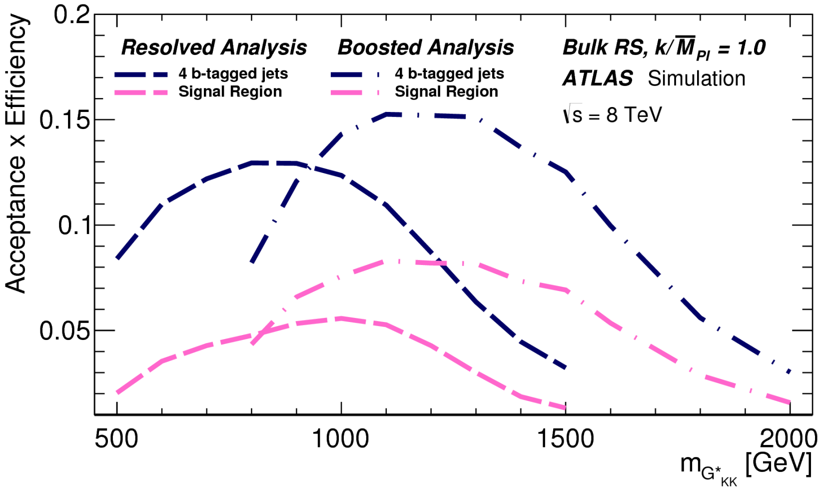
The algorithm attempts to catch each boson in a single C/A 1.2 jet and remove the QCD contamination.

Merged and Resolved Regime Efficiencies



Acceptance times efficiency for many signal hypothesis in the *WV* channel (upper) and the *ZV* channel (below) for merged and resolved regimes.

Merged and Resolved Regime Efficiencies



Acceptance times efficiency for different signal hypotheses for the $HH \to b\bar{b}b\bar{b}$.